Tunable Mode-Locked Laser Photonic Integrated Circuit Using Intracavity Phase Modulators

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Abstract: A 30 GHz mode-locked laser in PIC is presented using InP-based active-passive integration technology. The 2.8 mm long cavity contains phase modulators enabling sub-nm fine tuning of the lasing spectrum which is experimentally demonstrated.

OCIS codes: (140.4050) Mode-locked lasers; (140.5960) Semiconductor lasers; (250.5300) Photonic integrated circuits.

1. Introduction

Mode-locked lasers (MLL) have been of interest for its wide applications such as microwave photonics, optical communications and sensing where ultrashort optical pulses or coherent optical frequency comb are required [1]. MLL can be realized in the form of photonic integrated circuits (PIC) for an improvement in terms of compactness, robustness and power consumption [2]. Due to the inherently short cavity gigahertz (GHz) and millimeter waves (mmw) frequencies have been reached using monolithic MLL chip [3]. However, its tunability of mode position is relatively limited which hinders the spectral alignment to WDM (wavelength division multiplexing) channel passbands [4].

In this paper, we propose a MLL PIC that allows for precise spectral positioning of the longitudinal modes and supports repetition rates of 30 GHz in the optical output around 1560 nm. The tuning of wavelength position and free spectral range (FSR) is enable by modulating the refractive index of the arranged phase modulator waveguides. Proof-of-concept optical spectra, electrical spectra and autocorrelation traces are shown.

2. Device description

This PIC is designed using a generic approach for InP-based PICs and fabricated within a multi-project wafer (MPW) run by SMART Photonics [5], where a selection of optoelectronic components is provided as predefined standard building blocks [2]. The PIC as presented in Figure 1 (a) comprises a saturable absorbor (SA), semiconductor optical amplifiers (SOA), electro-optic phase modulators (EOPM), multimode interference reflectors (MIR) and straight/bent passive waveguides in a symmetric geometry with respect to the SA. This symmetry configuration assures operation in colliding pulse mode-locking regime, and the total cavity length is 2.8 mm corresponding to a repetition rate of 30 GHz. This 20 μm SA is surround by two 300 μm SOAs, both sharing the same electrical contact for injection from the same current source.

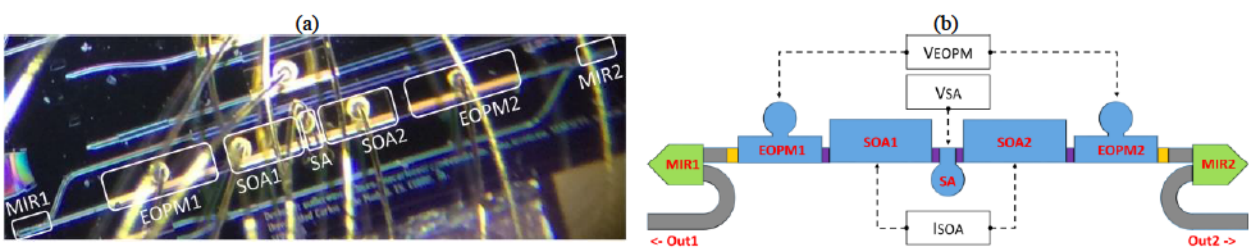

Figure 1 (a) Microscope view of PIC. (b) Schematic diagram of PIC.

As depicted in Figure 1 (b) the pair of 500 μm EOPMs enables the mode position tuning, each is wire-bonded to short-circuited metal tracks for same reverse bias voltage from one single voltage source. These active components are separated by 20 μm long isolation sections (purple) to prevent unwanted current flows. To form a complete cavity, passive straight waveguides are inserted with MIRs placed at the end acting as mirrors. At the other output of MIRs bent waveguides are to guide the beams out of the cavity towards the edge of chip. The passive waveguides (gray) and MIRs are made using deeply etched waveguides that have relatively low loss of 5 dB/cm and allow for smaller bending radius of 100 μm. Between the shallowly and deeply etched waveguides, transition sections (yellow) have to be used to minimize the butt-joint loss and back reflection.

3. Experimental setup

The PIC was mounted on a carrier and electrical contacts were wire-bonded to a track board as presented in Figure 2 (a). Cascade 12-pin probe bridged the tracks to electrical sources. The metal carrier was under thermoelectric cooling (TEC) control at 17.6 °C by Thorlabs PRO8000 TEC Controller. Isoa is controlled by PRO8000 Thorlabs LD Controller while Vsa and Veopm are reversely fed by Agilent E3634A Power Supplies. The optical output signal was collected via an Oz Optics lensed fiber and sent to the measurement instruments.
As presented in Figure 2 (b), Yokogawa AQ6370B optical spectrum analyzer (OSA), Anritsu MS2668C electrical spectrum analyzer (ESA) and APE PulseCheck autocorrelator (AC) were used, respectively. We arranged Amonics EDFA (erbium doped fiber amplifier) and a polarization controller (PC) before the autocorrelator so that the output power was increased to 10 dBm with controlled polarization state. For the electrical beat tone measurement, Nortel EDFA with 10 dBm output power and u2t photodiode (PD) with 40 GHz bandwidth were employed. For all results presented in this paper Vsa was set to 2.6 V and Isoa 74.5 mA because of the stable mode-locking operation. Veopm was swept from 0 to 6 V.

(a) (b)

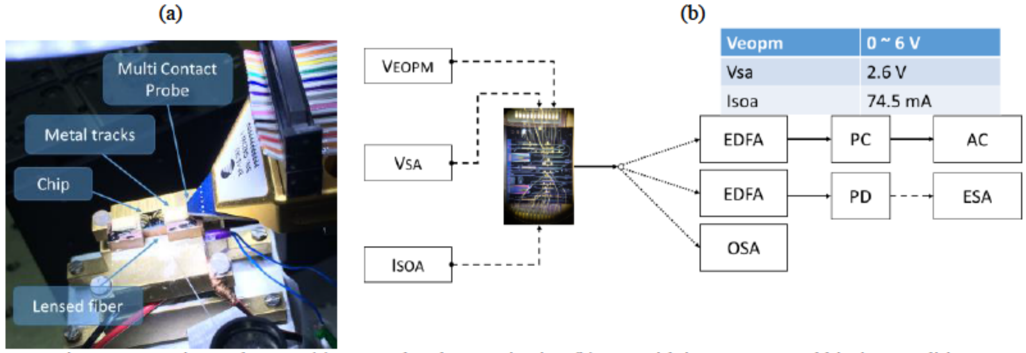

Figure 2 Experimental setup: (a) PIC under characterization (b) PIC with instruments and biasing condition

4. Result and discussion

At such a biaising condition, the average optical power coupled into a lensed fiber was stronger than 100 μW, and the multimode spectrum with a full width at half maximum (FWHM) of 3 nm around 1559 nm as shown in Figure 3 (a) was recorded using OSA with 0.02 nm resolution. The comb has a signal-to-noise ratio (SNR) of 30 dB and side-mode-suppression ratio (SMSR) of 15 dB. It was resolved that the in the comb lasing modes have a FSR of 0.24 nm corresponding to 30 GHz, while the suppressed supermodes are separated from adjacent lasing modes by 0.12 nm corresponding to 15 GHz as shown in Figure 3 (b). Detailed spectra of these two comb lines with two supermodes were recorded for each Veopm applied with a step of 2 V, showing the impact of Veopm on the spectral shift. As Veopm increase the spectrum is red-shifting. The horizontal position of blue (6V) and red (0V) differs by 0.024 nm and the SMSR decreases by 5 dB.

(a) (b)

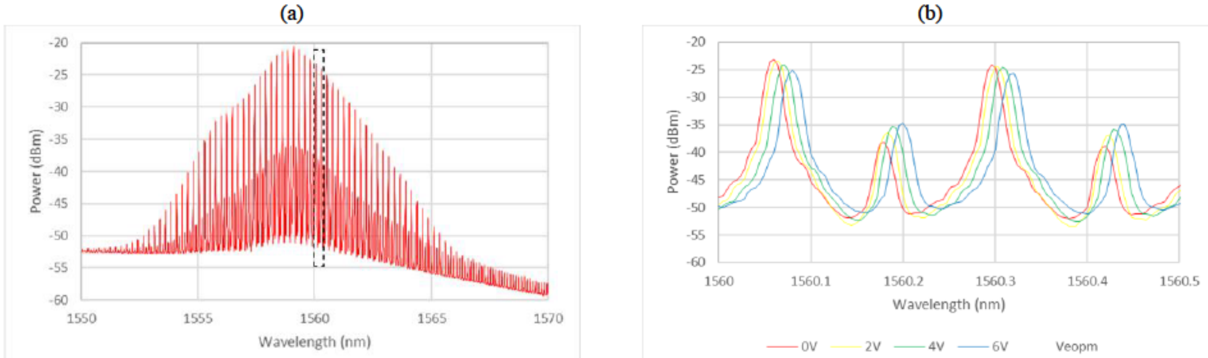

Figure 3 Optical spectrum: (a) full-span, Veopm = 0 V. (b) zoomed view, Veopm = 0, 2, 4, and 6 V.

A full-span (40 GHz) electrical spectrum is presented in Figure 4 (a) where the beat tone generated via PD was recorded using ESA with 30 kHz resolution bandwidth (RBW) and 3 kHz video bandwidth (VBH). A tone stands at 29.5 GHz that is the repetition rate of pulsed laser, with 60 dB signal noise ratio (SNR). There are Q switching-like spurs around the fundamental frequency 15 GHz and the presence of component in low frequency demonstrates amplitude modulation. In Figure 4 (b) a series of detailed beat tones produced on the PD with Veopm swept from 0 to 6 V were recorded. The impact on the tone of Veopm is apparently shown. The repetition rate nonlinearly decreases as Veopm increases. The blue (6V) peak is situated at 29.515 GHz and the red (0V) is 29.522 GHz, separated by 7 MHz. The 430 KHz linewidth and SNR do not have significant change as Veopm varies.

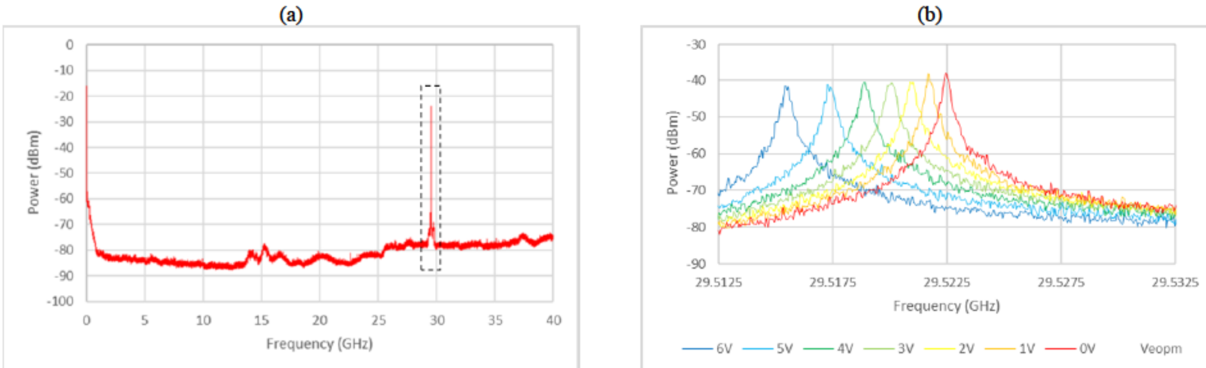

Figure 4 Electrical spectrum: (a) full-span, Veopm = 0 V. (b) zoomed view, Veopm = 0, 2, 4, and 6 V.

This 29.5 GHz periodic signal is confirmed by a second harmonic generation based autocorrelation (SHG-AC) trace presented in Figure 5 (a) where it shows a clear optical pulse train with a low background noise. Within the span of 150 ps, the delay between adjacent peaks is 33.9 ps that is in agreement with the beat tone frequency of 29.5 GHz in Figure 4. In Figure 5 (b) within the span of 15 ps the estimated FWHM duration of single pulse by Gaussian-shaped fitting curve is around 3.4 ps. As for the impact of varied Veopm, the change of repetition rate cannot be observed on AC since the time resolution is not sufficient.

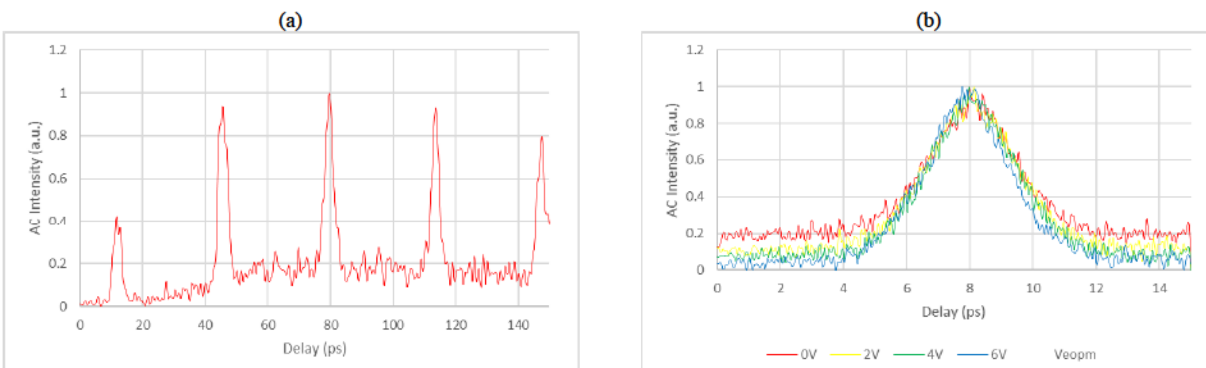

Figure 5 Autocorrelation: (a) span: 150 ps, Veopm = 0 V. (b) span: 15 ps, Veopm = 0, 2, 4, and 6 V.

5. Conclusion

A 30 GHz repetition rate mode-locked laser with tunable optical comb lines was developed as an InP photonic integrated circuit. The device operates in a passive mode-locking regime rate generating an optical frequency comb and the incorporated EOPMs enabling the spectral tuning. The optical comb exhibits a 0.024 nm FSR and 30 dB SNR. The characteristics of spectral tuning are demonstrated in terms of 0.024 nm wavelength shift and 7 MHz FSR tuning with 6 V bias voltage. The linewidth of beat tone is 430 KHz at 29.5 GHz.

It is expected that this tunable laser can be extended to a hybrid mode-locking version, in which only the wavelength position will be tuned but the FSR will be locked with injecting electrical signal frequency.

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References

[1] R. Kaiser and B. Huttl, "Monolithic 40-GHz mode-locked MQW DBR lasers for high-speed optical communication systems," IEEE J. Sel. Top Quantum Electron., vol. 13, pp. 125-135, 2007.

[2] M. K. Smit, X. Leijtens, E. Bente, J. van der Tol, H. Ambrosius, D. Robbins, M. J. Wale, N. Grote, and M. Schell, "A Generic Foundry Model for InP-based Photonic ICs," in Optical Fiber Communication Conference, (Optical Society of America, 2012), paper OM3E.3.

[3] C. Gordon; R. Guzman; V. Corral; M. C. Lo; G. Carpintero, "On-Chip Multiple Colliding Pulse Mode-Locked Semiconductor Laser," in Journal of Lightwave Technology , vol.PP, no.99, pp.1-1, 2016

[4] R. Zhou, S. Latkowski, J. O'Caroll, R. Phelan, L. P. Barry, and P. Anandarajah, "40nm wavelength tunable gainswitched optical comb source," Opt. Express 19, B415–B420 (2011).

[5] SMART Photonics B.V., http://www.smartphotonics.nl/.